Indoor solid fuel use for heating and cooking with blood pressure and hypertension: A cross-sectional study among middle-aged and older adults in China

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Abstract

A cross-sectional study was conducted to investigate the impact of solid fuel use for heating and cooking on blood pressure (BP) and hypertension, using data from the China Health and Retirement Longitudinal Study (CHARLS). The primary fuels used for indoor heating and cooking were collected by questionnaires, respectively. Hypertension was defined based on self-report of physician's diagnosis, and/or measured BP, and/or anti-hypertensive medication use. Multivariate logistic regression models were constructed to assess the associations. Among 10 450 eligible participants, 68.2% and 57.2% used indoor solid fuel for heating and cooking, respectively. Compared with none/clean fuel users, solid fuel for heating was associated with elevated BP (adjusted β: 2.02, 95% CI: 1.04–3.01 for systolic BP; adjusted β: 1.36, 95% CI: 0.78–1.94 for diastolic BP) and increased risk of hypertension (adjusted odds ratio: 1.15, 95% CI: 1.03–1.29). The impact of indoor solid fuel for heating on BP was more evident in rural and north residents, and hypertensive patients. We did not detect any significant associations between solid fuel use for cooking and BP/hypertension. Indoor solid fuel use is prevalent in China, especially in the rural areas. Its negative impact on BP suggested that modernization of household fuel use may help to reduce the burden of hypertension in China.

Keywords: blood pressure, Chinese, epidemiology, hypertension, indoor air pollution, solid fuel

Practical Implications

- Indoor solid fuel use for heating was associated with increased risk of systolic/diastolic BP and hypertension among middle-aged and older adults in China.
- The impact of indoor solid fuel for heating on BP seemed more evident among urban residents, individuals from northern China, and hypertensive patients.
- Indoor solid fuel is prevalent in China, especially in rural areas. Modernization of household fuel use may help to reduce the burden of hypertension.

Introduction

As a major public health concern worldwide, there were approximately 1.13 billion people with hypertension in 2015.[1] This figure was projected to rise to 1.56 billion people in 2025.[2] Hypertension is a well-established risk factor for cardiovascular disease (CVD) and mortality.[3, 4] It was estimated that hypertension was responsible for 9.4 million annual deaths worldwide.[5] Reductions in blood pressure (BP) could significantly lower the risk of CVD and all-cause mortality.[6] In China, the burden of hypertension is enormous. A nationwide study consisting of 1.7 million community-dwelling Chinese adults aged 35–75 years found that 45% of enrolled participants were suffering from hypertension, and that less than one-third were receiving prescribed medications.[7] Elevated systolic BP has been listed as one of the four leading risk factors contributing to deaths and disability-adjusted life years (DALYs) in China.[8]

In addition to age, smoking, unhealthy diet, obesity, and stress,[9, 10] exposure to air pollution has been associated with the risk of hypertension.[11, 12] A study among 39 million people of reproductive age identified significant association between exposure to outdoor fine particulate matter ($PM_{2.5}$) and the prevalence of hypertension.[11] Indoor air pollution has also been considered harmful to health possibly through the emission of a range of substantial toxic pollutants, such as carbon monoxide (CO), nitrogen dioxide (NO_2), $PM_{2.5}$, PM_{10}, black carbon, and several carcinogenic substances.[13, 14] Worldwide, over 3 billion people are using solid fuel for cooking and heating. Indoor combustion of solid fuel has been estimated to result in 4.5% of the global burden of disease.[15]

The association between indoor solid fuel use and hypertension has been investigated in studies with mixed findings.[16-22] A study conducted in Nepal showed that sustained use of biogas fuel for cooking could reduce the risk of high BP, especially for diastolic BP.[16] Another study of 4594 Chinese adults demonstrated that solid fuel users were linked to higher likelihood of having hypertension.[17] Similar findings were also reported in Indian and Peru.[18, 19] In contrast, an international study of 77 605 women from 10 countries showed that solid fuel use for cooking did not significantly increase the risk of hypertension.[20] Another cross-sectional study of 44 007 Chinese individuals aged between 35 and 70 years further distinguished indoor solid fuel use for cooking from that for heating in the analysis and found that its association with hypertension was not statistically significant.[21] A recent meta-analysis using data from nine observational studies concluded that household solid fuel use was associated with increased risk of hypertension.[22] However, further investigations are warranted given the significant heterogeneity of included studies.[22]

In this study, we investigated the association between self-reported solid fuel use for heating and cooking with BP and hypertension using data from the China Health and Retirement Longitudinal Study (CHARLS) survey.

Methods

Study design and participants

This cross-sectional study used data from the baseline survey of CHARLS, which was conducted between June 2011 and March 2012. The study design and sampling methods were reported in detail elsewhere.[23] In brief, CHARLS was a nationally representative study that included middle-aged and older population covering 450 rural villages and urban communities in 28 provinces of China. A multistage stratified probability sampling strategy with probability-proportional-to-size sampling technique was used. In total, 17 708 individuals were recruited at baseline.

CHARLS was approved by the Institutional Review Board (IRB) at Peking University, and each participant provided written consent. The IRB approval number for the main household survey, including anthropometrics, was IRB00001052-11015 and for the biomarker collection was IRB00001052-11014.[23]

Blood pressure-related measures

Systolic BP and diastolic BP of the study participants were measured from the left arm by trained nurses. The right arm was used unless measurements from the left arm were not feasible. Three BP readings were recorded with at least 45 s apart using a digital sphygmomanometer (OmronTM HEM-7200). The mean values of systolic BP and diastolic BP were calculated and used in the analysis. Hypertension was determined whether any of the following criteria were met: (1) systolic BP ≥140 mmHg; (2) diastolic BP ≥90 mmHg; (3) self-reported hypertension diagnosed by a physician; and (4) on anti-hypertensive medication.[24]

Indoor air pollution

For indoor fuel use, each participant reported the types of the main energy source for household heating and cooking through multiple-choice questions, respectively. Participants who reported "others" as their main fuel types for heating or cooking were excluded from the analysis due to the uncertainty about their actual indoor solid fuel exposure. We captured two types of indoor heating: (1) No heating/clean fuel user (i.e., without heating device in the household or use solar, natural gas, liquefied petroleum gas, or electricity as the main heating fuel); and (2) solid fuel users (i.e., with coal or crop residue/wood burning as the main heating energy source). The indoor fuel use for cooking was also classified into either clean fuel users (i.e., natural gas, marsh gas, liquefied petroleum gas, or electricity) or solid fuel users (i.e., coal, crop residue, or wood).

Covariates

Information on demographic and lifestyle data including age, gender (male and female), smoking status (never-, ex-, and current smoker), drinking status (never-, ex-, and current drinker), residence (rural and urban), and current marriage status (unmarried, married, or cohabitated) were obtained through face-to-face interviews by trained investigators. The area of residence was divided into urban and rural areas according to the classification of the villages or neighborhood communities by the National Bureau of Statistics of China.[25]

Standing height and weight were measured by validated stadiometer (SecaTM213) and scale (Omron TM HN-286 scale), respectively. BMI was calculated as weight (kg) divided by the square of height (m^2). Obesity was defined as BMI ≥28kg/m² based on the criteria for Chinese adults.[26] Waist circumference (WC) was measured with the soft measure tape in 0.1 cm. Central obesity was defined as WC ≥90 cm in males and ≥85 cm in females.[27]

Diabetes mellitus (DM) was defined as fasting plasma glucose ≥7.0 mmol/L, random plasma glucose ≥11.1 mmol/L, HbA1C ≥6.5%, self-report of a physician's diagnosis, or on glucose-lowering drugs/insulin treatment.[28] Physician-diagnosed dyslipidemia, chronic heart problems, and stroke were self-reported by the participants. CVD was defined as having chronic heart problems, stroke, or both.

Statistical Analysis

The characteristics of the study population were compared between different fuel groups for indoor heating and cooking, respectively. Continuous variables were described as mean ± standard deviation (SD), and the differences were compared by independent t tests. Categorical variables were described as frequency (percentages), and the differences were compared by chi-square tests.

The associations between indoor fuel types for heating and cooking with BP levels were assessed using multivariate linear regression models, while the impact of indoor fuel use on the presence of hypertension was evaluated with multivariate logistic regression models. We constructed three models for both linear and logistic regression analyses, respectively. Model 1 was adjusted for age, gender, and BMI. Model 2 was further adjusted for smoking and drinking status, regions, marriage, area of residence, CVD, DM, dyslipidemia, and anti-hypertensive drug use when the outcomes were systolic or diastolic BP. Model 3 was adjusted for all covariates in Model 2 and indoor fuel type for cooking when the exposure was indoor fuel use for heating, or indoor fuel type for heating when the exposure was indoor fuel use for cooking. Results were reported as β with 95% confidence intervals (CI) for linear regression models and adjusted odds ratios (aORs) with 95% CI for logistic regression models. Subgroup analyses were performed by gender (male and female), residence (rural and urban), geographic location (north and south), and hypertension status (when the outcomes were systolic BP or diastolic BP).

All analyses were performed using Stata Statistical Software Version 15.0 (StataCorp LLC). A two-sided p value <0.05 was considered as statistically significant.

Results

Of the 17 708 recruited participants, we excluded 488 participants aged under 45 years or without age information, 3147 participants without data on indoor air pollution or reported others as their main energy source for household heating and cooking, 3078 participants without BP assessment, and 545 without information of the confounders adjusted in the multivariate analyses (Figure 1). A total of 10 450 participants were included in the final analysis, 52.5% of whom were female. The average age of included participants was 59.3 (SD: 9.4) years. Table 1 shows the comparison of characteristics between different groups of indoor heating. Approximately, 68.2% of the participants used indoor solid fuel for heating. In general, participants used solid fuel for indoor heating were older, more likely to be current smokers, lived in rural areas, and had smaller BMI and waist circumference than those without heating device or used clean fuel for heating. In addition, solid fuel use for heating was associated with higher mean systolic BP, but only with borderline significance (p = 0.055). The prevalence of hypertension was comparable between the two groups (41.3% in no heating/clean fuel users; 40.8% in solid fuel users; p = 0.628).

In terms of the indoor fuel use for cooking, 5973 (57.2%) participants used solid fuel, and they were older compared with clean fuel users (Table 2). The proportion of females was comparable between the two groups. Compared with those who used clean fuel for indoor cooking, more solid cooking fuel users were current smokers and lived in rural areas. BMI and waist circumferences were also lower in solid fuel users than clean fuel users, which was similar to the comparison in different groups for indoor heating. We found no significant differences in systolic BP between groups. However, diastolic BP was significantly higher among users of clean fuel for cooking (76.50 ± 12.11 mmHg vs 75.82 ± 12.27 mmHg, p = 0.005). Additionally, the proportion of hypertension and dyslipidemia was significantly higher in clean fuel users compared with solid fuel users for cooking.

The associations between indoor fuel use for heating and cooking with BP and hypertension are presented in Table 3. In Model 1, we observed that participants used solid fuel for heating had 1.46 mmHg (95% CI: 0.61–2.30) higher systolic BP and 1.13 mmHg (95% CI: 0.64–1.62) higher diastolic BP than participants who did not use any heating device or used clean fuel for indoor heating. With further adjustment for confounders in Model 2 and Model 3, the detrimental effect of solid fuel use for indoor heating on both systolic and diastolic BP was still statistically significant. In terms of the association between fuel use for indoor heating and hypertension, we found that solid fuel users had 15% increased risk of hypertension compared with the reference group in the fully adjusted model, that is, Model 3 (OR: 1.15, 95% CI: 1.03–1.29). However, we did not observe any significant associations of indoor fuel use for cooking and BP or hypertension.

Table 4 shows the results of subgroup analyses. The positive associations of indoor fuel use for heating with BP remained significant in both men and women. However, the magnitude of association was relatively higher in women for systolic BP, and higher in men for diastolic BP. In terms of the association between indoor heating with hypertension, significant results were observed in men, but not in women. We further conducted subgroup analysis by area of residence. The results revealed that the detrimental effects of solid fuel use for indoor heating on systolic BP, diastolic BP, and hypertension were relatively more evident among urban residents compared with those living in rural areas. Furthermore, solid fuel use for heating was associated with increased systolic and diastolic BP only in participants with hypertension, while non-significant associations were observed in normotensive individuals. In terms of differences in geographic location, we found that solid fuel use for heating was associated with higher risk of systolic BP (β: 2.41, 95% CI: 0.99–3.82) and hypertension (aOR: 1.20, 95% CI: 1.02–1.41) in residents in northern China, whereas solid fuel users who lived in the south had significantly increased systolic BP (β: 1.79, 95% CI: 0.37–3.22) and diastolic BP (β: 1.56, 95% CI: 0.74–2.39). Similar to the main findings among all participants, we did not find any significant association between indoor fuel use for cooking and BP/hypertension in any subgroup.

Discussion

In this nationwide cross-sectional study, we found that indoor solid fuel use for heating was significantly associated with elevated BP and risk of hypertension. In contrast, we did not find any significant association between indoor solid fuel use for cooking and BP/hypertension. We further observed a relatively higher effect estimates of indoor solid fuel use for heating on both systolic and diastolic BP among urban residents, individuals from the northern China, and hypertensive patients. In addition, solid fuel use for heating seemed to have larger impact on systolic BP in women compared with men, while for diastolic BP, the effect size was relatively larger in men than women.

Our study examined the effect of indoor solid fuel use for heating and cooking, respectively, which has been less investigated.[21] One similar study previously revealed that solid fuel use for indoor heating, or for indoor cooking, or the combined solid fuel use was not a significant contributor to either elevated BP levels or the presence of hypertension.[21] One possible explanation for the inconsistency between the two studies might be due to the different study populations. In our study, the participants were older, with more females and more rural residents. Also, there were fewer participants that had ever smoked or drunk. These characteristics were risk factors for hypertension and might lead to the differences in the associations reported between the two studies.[9, 10] Furthermore, the different confounders adjusted might be another reason for the heterogeneity. For example, we did not have data on detailed residential address of each participant, and therefore, we were unable to adjust for individual exposure to ambient air pollution, such as $PM_{2.5}$. Previous studies have demonstrated detrimental effects of both short- and long-term exposure to $PM_{2.5}$ on elevated BP levels.[29-31] Therefore, inclusion of ambient air pollution might dilute the significant association between indoor solid fuel use for heating and BP/hypertension observed in our study. We additionally extracted annual $PM_{2.5}$ concentration at city level from the Global Annual $PM_{2.5}$ Grids (spatial resolution: 1 km) from NASA.[32] However, further adjustment for the city-level annual $PM_{2.5}$ concentration did not materially change our results. The findings were also consistent with an earlier comparative study, which found that inclusion or exclusion of $PM_{2.5}$ from the multivariate models did not alter the non-significance of the associations between indoor solid fuel use with BP and hypertension.[21] Future efforts are needed to address the different in-depth impact of indoor heating and cooking on BP/hypertension.

We further assessed the combined effect of indoor solid fuel use for heating and cooking and found that the significant association seemed mainly driven by solid fuel use for indoor heating (adjusted OR: 1.19, 95% CI: 1.06–1.34, for the group with solid fuel for heating only; adjusted OR: 0.98, 95% CI: 0.81–1.19, for the group with solid fuel for cooking only; and adjusted OR: 1.11, 95% CI: 0.99–1.23, for the group with both solid fuel for heating and cooking), while indoor solid fuel use for cooking did not add any additional risk for elevated

BP. This might be caused by the phenomenon of fuel stacking, that is, using multiple fuel types in one household. A previous study conducted in three provinces in China showed that 38% of the rural residents used multiple fuel types for cooking, while this figure was 0% for indoor heating.[33] Therefore, there was a possibility of misclassification of indoor cooking fuel use in our study, which might play a role in the insignificant associations between indoor solid fuel use for cooking and BP/hypertension.

Subgroup analyses revealed that the risk estimates of indoor solid fuel for heating on BP were relatively higher in urban residents than those living in rural areas and were also higher in hypertensive patients than their normotensive counterparts. The findings were consistent with previous studies, which indicated a modification role of hypertensive status on the association between air pollution and BP.[34, 35] The differences might be explained by the larger proportion of participants with abnormal weight in urban areas (50% in urban areas versus 35% in rural areas) and hypertensive patients (50% in hypertensive patients versus 33% in normotensive participants). Previous studies have pointed out that abnormal weight might exacerbate the impact of air pollution on BP and hypertension.[36, 37] Therefore, we speculate that the toxic pollutants emitted by solid fuel use together with abnormal weight could lead to the increased risk estimates observed. However, it deserves further investigations. Furthermore, the effect estimates of the associations between indoor solid fuel use for heating with systolic BP and hypertension were relatively larger in north residents than those living in the southern China, which was consistent with a previous study.[38] It might be explained by the longer duration of indoor heating in the north China due to the cold weather.

Previous literature showed that the underlying mechanisms responsible for elevated BP and increased risk of hypertension among indoor solid fuel users include increased inflammation, oxidative stress, and vascular function impairment caused by the harmful pollutants,[39, 40] which subsequently led to elevated BP.[41, 42] In addition, indoor solid fuel burning is one source of toxic volatile organic compounds (VOCs),[43] a kind of organic chemicals that easily turn into vapors or gases. VOCs could be involved in metabolic processes and cause elevated BP.[43] Therefore, the significant association between indoor air pollution for heating and hypertension we observed is biologically plausible. However, we did not detect any significant associations between indoor solid fuel use for cooking and BP/hypertension, which was consistent with several previous studies.[20, 21, 44] This might be caused by three main reasons. Firstly, the original CHARLS study did not collect information on household ventilation. Presence of ventilation may reduce the harmful effect of indoor air pollutants on health.[45, 46] Secondly, the survey respondents might not be the one who actually cooked at home, and therefore, they might be free of exposures. Last but not least, although fuel stacking for cooking was prevalent especially in rural China, the lack of information might lead to misclassification. Future studies would need to collect information on the presence and types of ventilation, fuel stacking, and the extent to which subjects were exposed to indoor solid fuel.

The strengths of our study included using a large sample, allowing adequate power to assess the associations between indoor air pollution with BP and hypertension. In addition, the information on the indoor solid fuel use was collected separately for heating and cooking, which allowed us to examine the separate impact on outcomes. However, several limitations of the current study deserve discussions. First, this study had a cross-sectional design. Further longitudinal studies are needed to confirm the temporal associations between indoor solid fuel use with BP and hypertension. The changes in indoor fuel use on BP variation and hypertension also deserve further investigations. Second, approximately 40% of the participants were excluded from our study due to various exclusion criteria. Some of the characteristics between included and excluded participants were different (Supplementary Table S1), which might lead to selection bias. Therefore, generalizability of our results should be interpreted with cautions. We further imputed the missing variables with multiple imputation and re-analyzed the data. The significant associations of indoor solid fuel use for heating with BP and hypertension were still present, indicating the robustness of our findings (Supplementary Table S2 and S3). Third, although evidence has suggested the detrimental effect of $PM_{2.5}$ on BP,[11] we did not consider it in our analysis because the residential address was unavailable, and we were unable to accurately estimate the individual level exposure to $PM_{2.5}$. We additionally evaluated the annual $PM_{2.5}$ concentration at the city level and found that inclusion of city-level annual $PM_{2.5}$ exposure into the multivariate models did not alter the significant associations between indoor solid fuel use for heating with BP and hypertension. Furthermore, a previous study has shown that the conclusions on the association between indoor air pollution and BP were stable irrespective of the inclusion of individual-level $PM_{2.5}$ in the multivariate models.[21] Therefore, the absence of data on ambient air pollution at individual level shall not substantially affect the current findings. Fourth, although previous studies showed that longer exposure to indoor solid fuel use was associated with increased risk of hypertension,[47] such information was not available in our study. We were, therefore, unable to evaluate the exact cumulative effect of indoor solid fuel on BP and hypertension, especially for indoor heating. We additionally conduct subgroup analysis by geographic location as a surrogate to represent the length of solid fuel for heating, given that residents in north China often had longer duration of heating due to the cold weather. The findings confirmed that compared with those living in the south, adults from the northern China had slightly increased risk estimates for systolic BP and hypertension, but not for diastolic BP. Last but not least, we only considered the primary fuel used for indoor heating and cooking due to data unavailability. It is likely that one household could use multiple fuel types, which might cause misclassification in the exposure groups. Future studies should consider the possibility of fuel stacking.

In conclusion, in a nationwide cross-sectional study among Chinese adults aged 45 years or older, we found that indoor solid fuel use for heating was associated with increases in systolic/diastolic BP levels and increased risk of hypertension. No significant associations were observed between indoor fuel use for cooking and BP/hypertension. Our findings suggest that residents in urban areas, northern China, and those with hypertension should monitor their BP levels when using indoor solid fuel. Our study adds knowledge to the ongoing debates about the detrimental effect of indoor solid fuel use on BP and hypertension, with implications for further longitudinal investigations.

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Conflicts Of Interest

The authors declared that they have no conflict of interest.

Authors' Contributions

Li Lin contributed to data curation, formal analysis, and writing-original draft preparation. Harry Haoxiang Wang contributed to validation, writing the original draft, and funding acquisition. Yuewei Liu contributed to visualization, methodology, and writing the review and editing. Ciyong Lu contributed to visualization and writing the review and editing. Weiqing Chen contributed to visualization and writing the review and editing. Vivian Yawei Guo contributed to conceptualization, supervision, funding acquisition, writing the review and editing, and project administration.

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Table 1. Comparison of characteristics according to indoor fuel use for heating

	Indoor heating		
	No heating/clean fuel user	Solid fuel user	*p* value
N	3328	7122	
Demographic and lifestyle factors			
Mean age (years)	58.64 ± 9.63	59.65 ± 9.35	<0.001*
Gender, n (%)			0.904
Male	1,556 (46.8)	3,401 (47.8)	
Female	1,770 (53.2)	3,717 (52.2)	
Smoking status, n (%)			<0.001*
Non-smoker	2,102 (63.2)	4,136 (58.1)	
Ex-smoker	301 (9.0)	649 (9.1)	
Current smoker	925 (27.8)	2,337 (32.8)	
Drinking status, n (%)			0.763
Non-drinker	1,937 (58.2)	4,192 (58.9)	
Ex-drinker	272 (8.2)	587 (8.2)	
Current drinker	1,119 (33.6)	2,343 (32.9)	
Area of residence, n (%)			<0.001*
Rural	1,172 (35.2)	5,320 (74.7)	
Urban	2,156 (64.8)	1,802 (25.3)	
Current marriage status			0.415
Not married	410 (12.3)	918 (12.9)	
Married or cohabitated	2,918 (87.7)	6,204 (87.1)	
Clinical / biomedical parameters			
BMI (kg/m^2)	24.29 ± 4.04	23.19 ± 3.81	<0.001*
Obesity, n (%)	472 (14.2)	739 (10.4)	<0.001*
Waist circumference (cm)			
Female	86.91 ± 10.04	85.21 ± 10.32	<0.001*
Male	87.74 ± 9.99	84.11 ± 9.91	<0.001*
Central obesity, n (%)	1,618 (50.2)	2,753 (39.3)	<0.001*
Systolic BP (mmHg)	130.14 ± 20.82	131.01 ± 21.82	0.055
Diastolic BP (mmHg)	75.92 ± 12.03	76.20 ± 12.29	0.283
History of chronic diseases			
Hypertension	1,376 (41.3)	2,909 (40.8)	0.628
Diabetes mellitus	460 (13.8)	878 (12.3)	0.033*
Dyslipidemia	405 (12.2)	597 (8.4)	<0.001*
CVD	456 (13.7)	1,011 (14.2)	0.499

Abbreviation: BMI: Body Mass Index; BP: Blood Pressure; CVD: Cardiovascular Disease.

Data were reported as mean ± SD or number (percentage), where appropriate.

$^*P$ <0.05.

Table 2. Comparison of characteristics according to indoor fuel use for cooking

	Indoor cooking		
	Clean fuel	Solid fuel	*p* value
N	4477	5973	
Demographic and lifestyle factors			
Mean age (years)	58.55 ± 9.52	59.92 ± 9.35	<0.001*
Gender, n (%)			0.540
Male	2,108 (47.1)	2,849 (47.7)	
Female	2,366 (52.9)	3,121 (52.3)	
Smoking status, n (%)			<0.001*
Non-smoker	2,767 (61.8)	3,471 (58.1)	
Ex-smoker	414 (9.2)	536 (9.0)	
Current smoker	1,296 (28.9)	1,966 (32.9)	
Drinking status, n (%)			0.024*
Non-drinker	2,624 (58.6)	3,505 (58.7)	
Ex-drinker	333 (7.4)	526 (8.8)	
Current drinker	1,520 (34.0)	1,942 (32.5)	
Area of residence, n (%)			<0.001*
Rural	1,798 (40.2)	4,694 (78.6)	
Urban	2,679 (59.8)	1,279 (21.4)	
Current marriage status			0.596
Not married	560 (12.5)	768 (12.9)	
Married or cohabitated	3,917 (87.5)	5,205 (87.1)	
Clinical / biomedical measures			
BMI (kg/m^2)	24.12 ± 4.00	23.10 ± 3.80	<0.001*
Obesity, n (%)	620 (13.8)	591 (9.9)	<0.001*
Waist circumference (cm)			
Female	86.72 ± 10.25	85.02 ± 10.21	<0.001*
Male	87.30 ± 10.15	83.72 ± 9.76	<0.001*
Central obesity, n (%)	2,133 (48.8)	2,238 (38.2)	<0.001*
Systolic BP (mmHg)	130.73 ± 21.08	130.74 ± 21.83	0.978
Diastolic BP (mmHg)	76.50 ± 12.11	75.82 ± 12.27	0.005*
Chronic diseases			
Hypertension	1,893 (42.3)	2,392 (40.0)	0.021*
Diabetes mellitus	595 (13.3)	743 (12.4)	0.198
Dyslipidemia	531 (11.9)	471 (7.9)	<0.001*
CVD	663 (14.8)	804 (13.5)	0.050

Abbreviation: BMI: Body Mass Index; BP: Blood Pressure; CVD: Cardiovascular Disease.
Continuous data were reported as mean ± SD or number (percentage), where appropriate.
$^{*}P$ <0.05.

Table 3. Associations between indoor solid fuel use for heating and cooking with blood pressure and hypertension

	SBP β (95%CI)	DBP β (95%CI)	Hypertension aOR (95%CI)
Heating [a]			
Model 1	1.46 (0.61, 2.30) *	1.13 (0.64, 1.62) *	1.08 (0.98, 1.18)
Model 2	1.97 (1.08, 2.85) *	1.27 (0.75, 1.79) *	1.12 (1.01, 1.24) *
Model 3	2.02 (1.04, 3.01) *	1.36 (0.78, 1.94) *	1.15 (1.03, 1.29) *
Cooking [b]			
Model 1	0.26 (-0.53, 1.06)	0.12 (-0.35, 0.58)	0.96 (0.88, 1.04)
Model 2	0.71 (-0.12, 1.55)	0.36 (-0.13, 0.85)	1.00 (0.91, 1.09)
Model 3	-0.12 (-1.05, 0.81)	-0.20 (-0.75, 0.34)	0.94 (0.85, 1.04)

Model 1: Adjusted for age, gender and BMI.

Model 2: Additionally adjusted for smoking and drinking status, marriage, region, area of residence, CVD, DM, dyslipidemia and anti-hypertensive drug when the outcomes was systolic or diastolic BP.

Model 3: Additionally adjusted for indoor cooking when the exposure was indoor heating; or additionally adjust for indoor heating when the exposure was indoor cooking

[a] Reference: No heating/clean fuel user for heating

[b] Reference: Clean fuel user for cooking.

*p<0.05

Table 4. Subgroup analysis on the association between solid indoor fuel use for heating and cooking with blood pressure and hypertension

	SBP β (95%CI)	DBP β (95%CI)	Hypertension aOR (95%CI)
Heating [a]			
Gender			
Male	1.86 (0.45, 3.26) *	1.57 (0.71, 2.43) *	1.19 (1.01, 1.40) *
Female	2.08 (0.71, 3.45) *	1.14 (0.36, 1.92) *	1.12 (0.96, 1.30)
Area of residence			
Urban	3.16 (1.71, 4.61) *	2.05 (1.21, 2.90) *	1.24 (1.06, 1.46) *
Rural	0.96 (-0.41, 2.34)	0.78 (-0.03, 1.60)	1.04 (0.89, 1.22)
Geographic location			
North	2.41 (0.99, 3.82) *	0.82 (-0.02, 1.67)	1.20 (1.02, 1.41) *
South	1.79 (0.37, 3.22) *	1.56 (0.74, 2.39) *	1.08 (0.92, 1.27)
Hypertension			
Yes	1.84 (0.34, 3.35) *	0.97 (0.09, 1.85) *	NA
No	0.44 (-0.27, 1.16)	0.48 (-0.06, 1.02)	NA
Cooking [b]			
Gender			
Male	-0.80 (-2.11, 0.51)	-0.55 (-1.35, 0.26)	0.87 (0.75, 1.02)
Female	0.53 (-0.77, 1.83)	0.12 (-0.62, 0.86)	1.01 (0.87, 1.16)
Area of residence			
Urban	0.09 (-1.46, 1.65)	-0.77 (-1.67, 0.14)	0.94 (0.79, 1.12)
Rural	-0.11 (-1.28, 1.05)	0.10 (-0.59, 0.79)	0.93 (0.82, 1.06)
Geographic location			
North	-0.69 (-1.94, 0.56)	-0.71 (-1.46, 0.04)	0.93 (0.80, 1.07)
South	0.03 (-1.34, 1.39)	0.03 (-0.76, 0.82)	0.91 (0.78, 1.06)
Hypertension			
Yes	0.13 (-1.28, 1.54)	-0.27 (-1.09, 0.55)	NA
No	0.08 (-0.59, 0.75)	-0.06 (-0.57, 0.45)	NA

Model adjusted for age, gender, BMI, smoking and drinking status, marriage, region, area of residence, CVD, DM, dyslipidemia, anti-hypertensive drug when the outcomes was systolic or diastolic BP, and indoor cooking when the exposure was indoor heating, or indoor heating when the exposure was indoor cooking.

NA: Not applicable.

[a] Reference: No heating/clean fuel user for heating; [b] Reference: Clean fuel user for cooking.

*p<0.05

Figure 1 Study Flowchart